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PROCEDURE

SEDIMENT STORAGE REQUIREMENTS FOR RESERVOIRS

PROCEDURE FOR DEVELOPING SEDIMENT STORAGE REQUIREMENTS FOR RESERVOIRS

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PROCEDURE FOR DEVELOPING SEDIMENT STORAGE REQUIREMENTS FOR RESERVOIRS

GENERAL

To assure the full effectiveness of a reservoir, capacity must be provided in it to offset the depletion of capacity due to sediment accumulation during its design life. Engineering Memorandum-27 (Rev), Supplement 1, establishes the criteria and general procedures needed to determine the required volume of sediment accumulation and its allocation above and below the crest elevation of the principle spillway. Form SCS-309 (Rev. 10-67), Reservoir Sedimentation Design Summary, has been prepared to facilitate recording and computation of the data. This form, figure 1, should be completed by a geologist familiar with the processes of sedimentation. When the form is properly filled out, the design criteria set forth in Engineering Memorandum-27 (Rev), Supplement 1, will be met. A copy of the form should be prepared and filed with other pertinent design information for each reservoir. The recorded data then will be available for use in the final design of reservoirs proposed for either watershed or other program work plans.

Engineering Memorandum-27 (Rev), Supplement 1, states: "The rate of sediment accumulation in a reservoir is dependent on the sediment yield from its drainage area ...." This infers that the sediment yield, as such, must be determined for each reservoir that is being designed. It does not, however, preclude the use of available information concerning rates of sediment accumulation in reservoirs.

The following discussion considers the principles and procedures involved in the sediment design of reservoirs encountered in Service work. Examples to indicate the proper completion of Form SCS-309 (Rev. 10-67) are presented for several types of reservoirs. Methods and procedures referred to but not included in this Technical Release are to conform with National procedures or with procedures approved by the Engineering and Watershed Planning Units.

SEDIMENT YIELDS

There are several ways to determine sediemnt yields or rates of sediment accumulation in reservoirs and these are discussed briefly below.

Gross Erosion and Sediment Delivery Ratios

This means of determining sediment yields has proven quite successful in Service work especially in the more humid areas of the country. It is well adapted for estimating current sediment yields and predicting the influence and effect of land treatment and other measures on future sediment yields. The following simple equation is employed and the sediment yield part of Form SCS-309 (Rev. 10-67) has been designed with this equation in mind.

$$Y = E(DR) \qquad \text{(Equation 1)}$$

SCS-309
Rev. 10-67

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

RESERVOIR SEDIMENTATION DESIGN SUMMARY

WATERSHED ______________________ SITE NO. ________ DRAINAGE AREA ________ Sq. Mi. ________ Acres

LOCATION ______________________ STATE ________ PURPOSE ______________________

DATA COMPUTED BY ______________________ TITLE ______________________ DATE ________

SEDIMENT YIELD BY SOURCES (AVERAGE ANNUAL)

		PRESENT CONDITIONS			FUTURE (AFTER CONS. TREATMENT)		
		ACRES	SOIL LOSS (TONS/AC)	TOTAL (TONS)	ACRES	SOIL LOSS (TONS/AC)	TOTAL (TONS)
SHEET EROSION	CULTIVATED LAND						
	IDLE LAND						
	PASTURE - RANGE						
	WOODLAND						
	OTHER						

	DELIVERY RATIO (%)		TONS DELIVERED	DELIVERY RATIO (%)		TONS DELIVERED
SHEET EROSION - TOTAL						
GULLY EROSION						
STREAMBANK EROSION						
STREAMBED EROSION						
FLOODPLAIN SCOUR						
OTHER (ROADSIDE ETC.)						
		TOTAL			TOTAL	

DEPOSITION

TEXTURE INCOMING SEDIMENT		
% CLAY	% SILT	% COARSE
VOLUME WEIGHT DEPOSITED SEDIMENT LBS/CU. FT.		
SUBMERGED		
AERATED		

	SEDIMENT DELIVERED TO SITE (TONS/YR)	TRAP EFFICIENCY (%)	ANNUAL DEPOSITION (TONS)	DESIGN PERIOD (YRS)	PERIOD DEPOSITION (TONS)	DESIGN DEPOSITION (TONS)
PRESENT						
FUTURE						
FUTURE						
			TOTALS			

SEDIMENT STORAGE REQUIREMENTS

PERIOD (YRS)	CONDITION OF SEDIMENT	% OF TOTAL	DEPOSITION (TONS)	VOLUME WEIGHT	STORAGE REQUIRED		STORAGE ALLOCATION (ACRE FEET)		
				TONS/AC.FT.	ACRE-FEET	WATERSHED INCHES	SEDIMENT POOL	RETARDING POOL	OTHER
	SUBMERGED								
	AERATED								
	SUBMERGED								
	AERATED								
		TOTALS							

Figure 1. Reservoir Sedimentation Design Summary

where: Y = Sediment Yield (tons/unit area/year)
E = Gross Erosion (tons/per unit area/year)
DR = Sediment Delivery Ratio (DR less than 1)

The gross or total erosion in the drainage area of a reservoir is the summation of all erosion occurring in the drainage area. It includes sheet and rill erosion and channel-type erosion (gullies, valley trenches, streambank erosion, etc.). The determination of quantitative values for each type of erosion is outlined in existing guides, handbooks, and technical releases. The sediment delivery ratio, the ratio of sediment yield to gross erosion, is estimated from relationships discussed in various guides and references. The product of the gross erosion and the sediment delivery ratio provides the sediment yield for use in computing the sediment design requirements.

Reservoir Sedimentation Surveys

Reservoir sedimentation surveys are excellent sources of data for establishing sediment yields to reservoirs. Reservoir deposition and sediment yield are not synonymous. To obtain the sediment yield to a surveyed reservoir, the measured rate of deposition in that reservoir must be divided by its estimated trap efficiency. This takes into account that portion of the sediment inflow that is not deposited in the reservoir but passes on through the outlet works. The use alone of the rate of deposition established by a sedimentation survey implies that the trap efficiency of the reservoir being designed is the same as that of the surveyed reservoir, and this is not necessarily the case.

If the results of reservoir sedimentation surveys are available, they may be used for design purposes. Miscellaneous Publication No. 964[1/] provides the data obtained from many reservoir surveys, and information concerning rates of deposition in selected reservoirs representing the area under consideration may be obtained from this publication. If no reservoirs representing the area have been surveyed, it could well prove profitable to conduct sedimentation surveys on selected reservoirs existing in the area. It is important that the period of sedimentation record of reservoirs previously surveyed or contemplated for survey be long enough to insure data that will represent the normal or average conditions.

The drainage areas of any reservoirs on which sedimentation surveys have been or are made for specific sediment design needs must be similar in topography, soils, and land use to that for which the information is desired. In addition, the size of the drainage areas of the surveyed reservoirs, should not be less than one-half nor more than

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1/ Summary of Reservoir Sediment Deposition Surveys Made in the United States Through 1960; Agricultural Research Service in cooperation with Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources; Miscellaneous Publication No. 964, U.S. Department of Agriculture, Washington, D. C., May 1964.

twice that of the particular structures being designed if the measured data is to be directly transposed. For drainage areas not within this limitation, the total annual sediment yield may be adjusted for design use on the basis of the ratio of the drainage areas raised to the 0.8 power in the following manner:

$$S_e = S_m \left(\frac{A_e}{A_m}\right)^{0.8} \qquad \text{(Equation 2)}$$

where: S_e = sediment yield to structure being designed, in tons per year

S_m = sediment yield to the surveyed reservoir, in tons per year: measured annual deposition ÷ trap efficiency of surveyed reservoir

A_e = drainage area of reservoir being designed

A_m = drainage area of surveyed reservoir

In consistently mountainous areas, such as the Sierra Nevada, there is no indicated difference in sediment yield per unit area due to size of drainage area. Also, where active channel-type erosion increases downstream as from mainstem channel bank cutting, the sediment yield per unit area may increase with increasing drainage area. Therefore, the relationship must be used with judgment and should be confined generally to the humid areas east of the Rocky Mountains.

Suspended Load Records

Rarely is there time available to establish a suspended load station at a proposed site and obtain sufficient data before the design information is required. However, if suspended load records are available from nearby locations that represent the areas for which the information is required, such data may be used similarly to that obtained by reservoir sedimentation surveys. In the instance of suspended load data, the bedload portion of the sediment yield is not measured, and estimates of this part of the sediment load must be made. It can vary from practically none to 15-20 percent or more of the total load depending upon the type of sediment that is available for transport by the stream.

Direct Predictive Equations

Predictive equations based on watershed and reservoir parameters have been developed in some areas to estimate sediment yield or reservoir sediment accumulation. These equations generally express sediment yield or reservoir sediment accumulation as functions of a combination of several measurable, independent variables. The variables may be reservoir capacity/watershed ratio, annual runoff, size of drainage area, reservoir shape, watershed shape, time, and others.

Such equations are not numerous but, where developed, they may be used with the understanding that their application must be confined to the specific area they represent.

SEDIMENT DEPOSITION

Sediment accumulation in a reservoir is dependent on the sediment yield from its watershed, the trap efficiency, and age of the reservoir. How the accumulated sediment will be distributed within the reservoir basin depends upon the character of the inflowing sediment, the operation of the reservoir, and other factors.

Trap Efficiency

Trap efficiency is the amount (in percent) of the sediment delivered to the site that will remain in the reservoir. It is a function of detention storage time, character of the sediment, nature and character of inflow, and other factors. The trap efficiency is readily estimated on the basis of the ratio of the capacity of the reservoir to the average annual inflow[2/] [3/] using the following procedure.

A. Estimate the total required capacity of the reservoir in inches. This includes the total capacity allocated to floodwater detention, sediment storage, and other uses. Since an actual value for the total capacity cannot be obtained until final design is completed, an approximation of the total capacity is made as follows.

   1. Assume, for the physiographic area involved, a reasonable and realistic volume of sediment storage that might be required for the effective life of the structure. For example, 1.5 inches.

   2. Obtain from the hydrologist an estimate of the required floodwater detention storage. For example, 4.5 inches.

   3. The sum of 1 and 2 is the estimated total capacity of the reservoir. That is, 1.5 + 4.5 = 6.0 inches. If there is additional storage such as storage for water supply, recreation, etc., it must be included in the estimated total. If an estimate of the total required storage is available in terms of acre-feet, it is suggested that this value be converted to watershed inches to simplify the calculation.

B. Determine the average annual runoff, in inches. This value may be from the hydrologic analysis of the watershed, from Hydrologic Investigation, Atlas HA-212[4/], or other available information.

2/ Brune, Gunnar M., Trap Efficiency of Reservoirs, Trans. AGU, Vol. 34, No. 3, pp. 407-418, June 1953.

3/ Gottschalk, L. C., Trap Efficiency of Small Floodwater-Retarding Structures, Conference Preprint 147, ASCE Water Resources Engineering Conference, Mobile, Alabama, March 8-12, 1965.

4/ Busby, Mark W., Annual Runoff in the Conterminous United States, Hydrologic Investigations, Atlas HA-212, U.S. Geological Survey, Washington, D. C., 1966.

For purposes of this illustration, it is estimated to be 17.5 inches.

C. Divide the approximate total capacity, in inches, item A-3 above, by the average annual runoff in inches, item B above, to obtain the capacity-inflow (C/I) ratio. That is, $6.0 \div 17.5 = 0.343$ C/I ratio.

D. Using the curves in figure 2, the trap efficiency for a given C/I ratio in percent is determined on the vertical axis of the graph. Where incoming sediment is assumed to have an abnormal grain-size distribution such as a predominance of bedload or coarse material or the sediment is highly flocculated, the upper curve of figure 2 should be used to determine the trap efficiency. If the incoming sediment is composed primarily of colloids, dispersed clays and fine silts, the lower curve should be used. The median curve is representative of incoming sediment consisting of a normal distribution of various grain sizes. The texture of the sediment should be estimated on the basis of character of watershed soils and the principal sources of sediment. This estimate will provide a basis for selecting the curve in figure 2 to use in determining the trap efficiency and will also have a bearing on the distribution and allocation of the sediment in various pools.

   The curves of figure 2 are not applicable to dry reservoirs without adjustment. Where water flows through ungated outlets below the crest of the principal spillway, trap efficiency may be greatly reduced depending on the size and number of such outlets. If the inflowing sediment is predominantly sand, trap efficiency should be reduced by about 10 percent; if it is chiefly fine textured, about 20 percent.

   If it is determined that the incoming sediment is composed essentially of equal parts of clay, silt, and fine sand and the proposed structure will have a submerged sediment pool, the median curve of figure 2 would be used without adjustment. In this instance, with a C/I ratio of 0.343, the trap efficiency would be 95 percent. In a similar situation except that the structure is designed as a dry reservoir, the trap efficiency would be 75 percent.

Design Life

The design life of a reservoir is considered equal to the period required for the reservoir to fulfill its intended purpose or purposes. Structures designed by the SCS in the Watershed Protection and Flood Prevention programs are normally designed for a design life of 50 or 100 years. No matter what length of time is involved for a particular reservoir, provisions must be made to accomodate the expected sediment deposition during the same period. This might involve periodic clean-out of deposited sediment at predetermined intervals during the design life or, as is generally the case, capacity is provided to store all of the expected sediment accumulation for the entire design life.

There are certain restrictions placed on the volume of water that may occupy, until displaced by sediment, the sediment pool of a single-

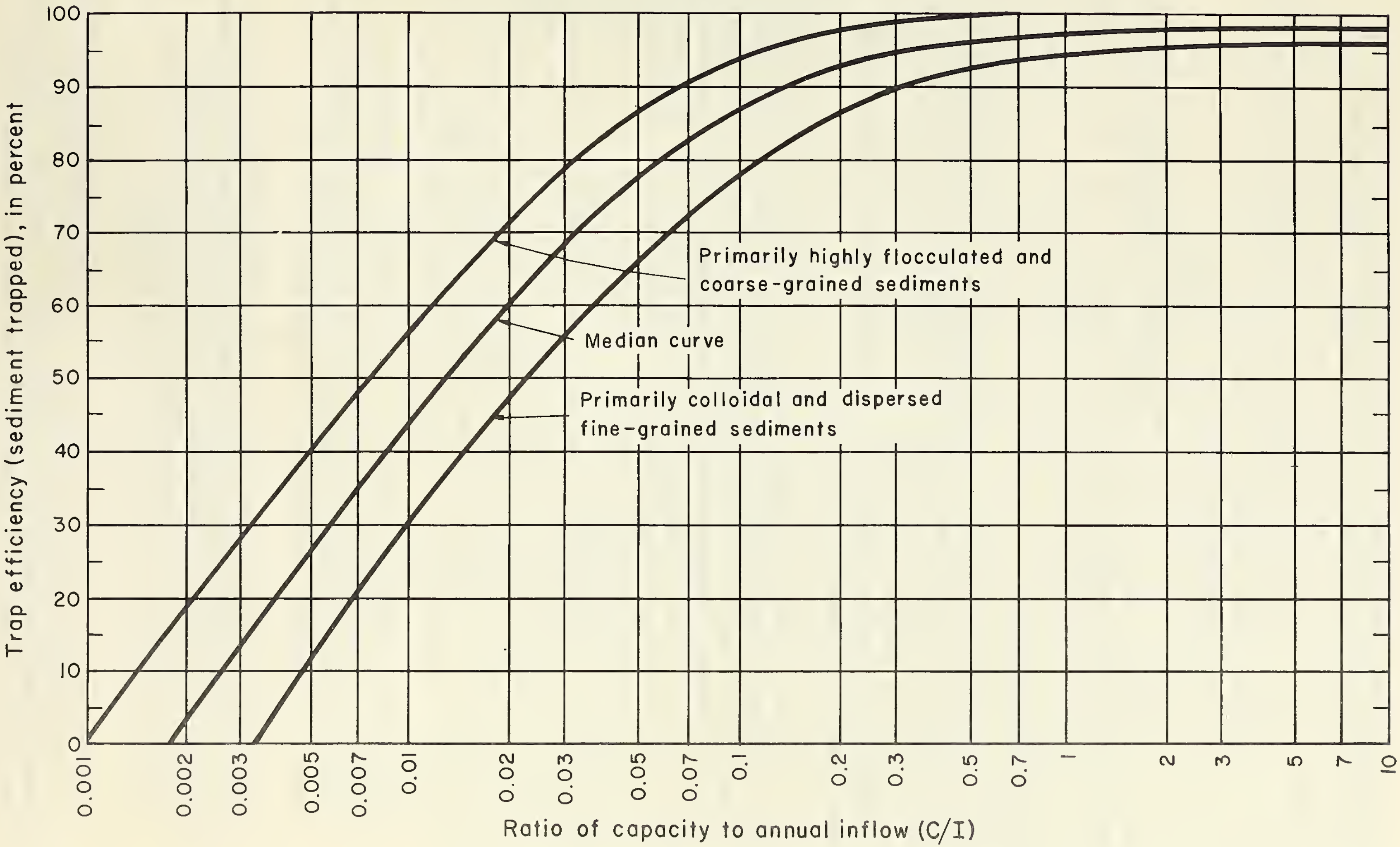

Figure 2. Trap efficiency of reservoirs

purpose floodwater retarding structure built with Federal funds. To meet these restrictions the design life of such a structure proposed for a 100-year life must be considered in two 50-year periods. In addition, the early part of the design life of any reservoir must be considered in terms of the anticipated number of years that will be required for proposed land treatment (conservation) measures to be installed, established, and fully effective in reducing erosion and sediment yield. This period, termed "Present Conditions," must be determined in consultation with the State Program Staff, Area and Work Unit Conservationists. Land treatment measures seldom become fully effective in less than 5 years. Often longer periods are required, and this delay in effectiveness must be recognized.

Distribution of Sediment

The purpose of sediment storage in a reservoir is to provide space for deposited sediment and to prevent the encroachment of sediment in required retarding or storage capacities. Consequently, an estimate must be made of the amount of sediment which will be deposited outside of the sediment pool because such deposits may materially affect the proper functioning of the structure.

The portion of the incoming sediment that will deposit above the elevation of the principal spillway will vary with the nature of the sediment, shape of the reservoir, topography of the reservoir floor, nature of the approach channel, detention time, and purpose of the reservoir. The coarser fractions of the sediment inflow will settle as the velocity of the transporting medium decreases. Generally, the periods of greatest sediment inflow occur at the time detention capacity is being used, thus deposition of sediment will occur at elevations above the principal spillway. Usually, a larger part of the sediment inflow will deposit above this elevation if a large part of it is composed of coarse material. The texture of the incoming sediment provides the basis for estimating the portion that will deposit above the elevation of the principal spillway for different sediment inflow characteristics. The following guidelines should be considered in making these estimates:

1. Watersheds of low to moderate relief where the predominant sources of sediment are silty and clayey soils, where sheet flow is the principal eroding agent and the sediment is transported primarily in suspension: 10 percent.

2. Watersheds of low to moderate relief, with combination sheet and channel-type erosion, where products of erosion are essentially equal amounts of medium to fine sands, silts, and clays. Transport of coarser materials is along the bed and finer materials are in suspension: 20 percent.

3. Watersheds of moderately high relief where channel-type erosion is the primary source of sediment. Substantial amounts of coarse sand and gravel are transported as bedload, with smaller amounts of fine-grained sediment transported in suspension: 30 percent.

4. Watersheds of high relief where the primary sediment load consists of boulders, cobbles, and sand: above 30 percent.

These percentages may be adjusted upward or downward, using judgment based on local watershed and reservoir conditions.

SEDIMENT STORAGE REQUIREMENTS

Capacity Requirements for Sediment

That portion of the incoming sediment that deposits in an underwater environment is termed "submerged" sediment. That which deposits above the elevation of the principal spillway is subject to alternate wetting and drying and is termed "aerated" sediment. The terms "submerged" and "aerated" are essentially synonymous with sediment pool and retarding pool, respectively, in a single-purpose floodwater retarding structure unless the structure is designed as a dry reservoir. In the latter instance all deposited sediment would be considered aerated.

The distinction between submerged and aerated sediments is important in terms of the capacity each will displace. The ultimate volume occupied by the deposited sediment will depend on its texture and whether it is submerged or subjected to alternate submergence and aeration. The volume weight of sediment, in pounds per cubic foot, is based on judgment where records are not available. The following table based on analysis of available data may be used as a guide to selection of volume weights where field measurements are not available.

Grain Size	Submerged (lbs/cu.ft.)	Aerated (lbs/cu.ft.)
Clay	40-60	60-80
Silt	55-75	75-85
Clay-silt mixtures (equal parts)	40-65	65-85
Sand-silt mixtures (equal parts)	75-95	95-110
Clay-silt-sand mixtures (equal parts)	50-80	80-100
Sand	85-100	85-100
Gravel	85-125	85-125
Poorly sorted sand and gravel	95-130	95-130

For any structure being designed, the volume weight, in pounds per cubic foot, of the deposited sediment must be estimated for each environment of deposition. Any volume of sediment determined on the basis of aerated volume weight will retain that same volume even though the sediment may be submerged later.

Sediment Storage Allocation

The required sediment storage must be allocated between the various pools of the reservoir. This is important as certain pool elevations

and flood-routing procedures are dependent upon the expected distribution of the sediment within the reservoir. Engineering Memorandum-27 (Rev.) provides the following definitions which must be kept in mind as the allocations are made. *Sediment storage* is the volume allocated to total sediment accumulation. The *sediment pool* is the reservoir space allotted to the accumulation of submerged sediment during the life of the structure. The *sediment pool elevation* is the elevation of the surface of the anticipated sediment accumulation at the dam. In addition, *sediment reserve* is defined as the volume of the sediment pool required for the second 50-year period in a single-purpose floodwater retarding reservoir designed for a 100-year life.

The following general guidelines are presented to assist in allocating the sediment storage for several situations. They are primarily concerned with reservoirs in which the major portion of the sediment will deposit in a submerged environment. If the structures are designed as "dry" reservoirs, the same guidelines will apply except that all sediment volumes will be based on aerated volume weights.

A. Single-Purpose Floodwater Retarding Reservoirs

1. Single-stage principal spillway

   a. In a 50-year life structure, the sediment pool elevation determines the crest elevation of the principal spillway. Since water is expected to occupy this space until displaced by sediment, the sediment volume will be computed using submerged volume weights. The volume of the sediment expected to deposit in the retarding pool will be computed using aerated weights.

   b. In a 100-year life structure, the sediment pool elevation as computed for the first 50-year period determines the crest elevation of the principal spillway to be constructed for this period. Since water is expected to occupy this space until displaced by sediment, the sediment volume will be computed using submerged volume weights.

      The volume of the sediment pool, or sediment reserve, required for the second 50-year period will also be determined by using submerged volume weights. This is necessary as it is assumed that structural modifications will be made to the principal spillway at the end of 50 years that will raise its elevation to that required for the additional amount of sediment. Submerged volume weights must be used as, with the assumed modifications, water is expected to occupy this capacity until displaced by sediment.

      During the first 50-year period, it is known that some sediment will deposit and be subjected to aeration in the capacity allotted to the sediment reserve. Depending on erosion rates, character of the sediment, and operation of the reservoir, this volume may be significant. It is

recommended that the geologist consider each structure individually and determine the need for such allocation.

2. Two-stage principal spillway

   a. In a 50-year life structure, the sediment pool elevation determines the elevation of the low-stage inlet of a two-stage principal spillway. Since water is expected to occupy this space until displaced by sediment, the volume will be computed using submerged volume weights.

      It is known that some sediment will deposit between the elevations of the low-stage and high-stage inlets. The geologist will determine the need for such allocation and will compute the volume using aerated volume weights. That portion of the sediment storage expected to occur in the retarding pool will be computed using aerated volume weights.

   b. In a 100-year life structure, the first 50-year sediment pool elevation determines the elevation of the crest of the low-stage inlet. Since water is expected to occupy this space until displaced by sediment, this volume will be computed by using submerged volume weights.

      The original construction plans of the principal spillway should provide for the crest of the high-stage inlet to be built at the elevation required at the end of the 100-year period. It is assumed that structural modifications will be made to the principal spillway at the end of 50 years to raise the elevation of the low-stage inlet to that required for the additional amount of sediment. Since it is assumed that water will occupy the space below this higher elevation of the low-stage inlet during the second 50-year period, the sediment volume will be computed using submerged volume weights.

      It is known that some of the sediment will deposit and be subjected to aeration in the retarding pool between the low and high-stage inlets as well as in that above the high-stage inlet. This will occur during both 50-year periods and a portion will be included in the capacity provided for submerged sediment during the second 50 years (sediment reserve). The geologist will make provisions for the capacity required below and above these several elevations for this sediment and the volume will be computed using aerated volume weights.

B. Multiple-Purpose Reservoirs

The sediment pool in multiple-purpose reservoirs will be planned as one pool for the entire evaluated economic life of the structure (normally one hundred years), and its volume will be based on submerged volume weights. The capacity for beneficial water storage

should be added to that required to contain the submerged sediment. The portion of the sediment that will deposit above the elevation of the principal spillway will be determined in accordance with the general guidelines previously discussed. The volume of such sediment will be computed on the basis of aerated volume weights.

A multiple-purpose structure may be designed with either a single-stage or two-stage principal spillway. If a two-stage principal spillway is used, consideration must be given to the distribution of the sediment between the elevations of the low and high-stage inlets as well as that above the elevation of the high-stage inlet. The volume of this sediment will be computed on the basis of aerated volume weights.

It is suggested that procedures for allocation of sediment storage considered necessary but not specifically covered in this Technical Release be developed in consultation with the Engineering and Watershed Planning Unit.

COMPLETION OF FORM SCS-309 (Rev. 10-67)

Certain basic background information is necessary concerning every reservoir being designed. The approximate location of the structure must be indicated on an aerial photograph, a USGS quadrangle, or other suitable map so that the watershed and problem areas above the site can be delineated and measured. An estimate of the total required reservoir capacity for all purposes must be made.

The several major parts of the form are considered separately in the following discussions.

1. Heading

Most of the information required in the heading is self-explanatory. The drainage area refers to the drainage area above the site of the structure. The purpose of the reservoir should be stated as: Single-purpose--flood prevention; Multiple-purpose--flood prevention and water supply; or whatever purpose may be involved. Any additional pertinent information concerning the structure such as single or two-stage riser should be noted in the space to the left and below the heading.

An example of the heading is shown below.

SCS-309
Rev. 10-67

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

RESERVOIR SEDIMENTATION DESIGN SUMMARY

WATERSHED Blank Creek SITE NO. 7 DRAINAGE AREA 3.44 Sq. Mi. 2200 Acres

LOCATION Photo No. ASI-131 STATE Midstate PURPOSE Single-purpose--FP

DATA COMPUTED BY James Jones TITLE Geologist DATE 12/15/67

2. Sediment Yield by Sources (Average Annual)

a. Gross Erosion and Sediment Delivery Ratios

As stated earlier, Form SCS-309 (Rev. 10-67) was designed with the relationship of gross erosion and sediment delivery ratios to sediment yield (Equation 1) in mind. Thus, this part of the form concerns estimates of erosion occurring in the drainage area of the reservoir and the sediment delivery ratios.

The estimates of the annual amounts of erosion must be realistic and reasonable, both for "Present conditions" and for "Future (After Conservation Treatment)." Normally these estimates are developed by delineating problem areas in the drainage area and computing sheet erosion and the other components of the total erosion as individual items. Separate work sheets are generally used for this purpose and only totals for each component of the erosion need be indicated in the appropriate spaces on the form. It would be preferable, however, to show the acreages and rates of soil loss for each land use listed under "Sheet Erosion." The "Soil Loss (Tons/Ac)" for sheet erosion values is to be developed in conformance with existing guides and releases prepared by the Engineering and Watershed Planning Units. The basic information required for this determination may be obtained from soil survey data available in Work Unit offices and any supplementary field investigations as may be necessary.

The "Future (After Conservation Treatment)" data should be computed using the most realistic information available. Land treatment data provided by the Work Unit Conservationist should be reflected in predicting reductions in erosion rates from the various sediment sources. These future reductions must be realistic and should be attainable.

The total amounts of material eroded by channel-type processes (gullies, streambanks, etc.) for both present and future conditions are estimated on the basis of field reconnaissance or detailed study using available aerial photographs and soil survey data. If the volume of sediment produced by gullying is determined by the procedure outlined in Technical Release No. 32, "Procedures for Determining Rates of Land Damage, Land Depreciation and Volume of Sediment Produced by Gully Erosion," dated July 1966, the tons of eroded material so obtained should be used. Information concerning streambank erosion and flood-plain scour often can be obtained from the flood-plain damage survey. If the streambed is degrading and is a source of sediment, procedures to determine annual amounts of streambed erosion should be developed in consultation with the Engineering and Watershed Planning Unit. The total amount of material eroded by these processes is entered in the appropriate spaces on the form. The work sheets used

in developing the erosion information should be filed with Form SCS-309 (Rev. 10-67) as supporting data.

The next step in completing this part of the form is concerned with sediment delivery ratios and the computation of sediment yield at the structure site. The percent of eroded material that reaches the site should be realistically estimated for each component of the erosion. Various guides for estimating sediment delivery ratios in terms of watershed parameters have been prepared by the several Engineering and Watershed Planning Units, and these guides should be consulted to obtain values to enter in the appropriate spaces. The item "Tons Delivered" is the product of the total soil loss for each component of the erosion and the "Delivery Ratio (%)" for that component. The sum of these products is the sediment yield for "Present" and "Future" conditions.

Where upstream structures control sediment, the erosion and sediment yield are determined using the foregoing procedure only for the net drainage area below the upstream structures.

b. Data from Reservoir Sedimentation Surveys

If sediment yields based on transposed data obtained from reservoir sedimentation surveys are to be used, the values so obtained are entered in the total "Tons Delivered" spaces of this part of the form. Unless there is strong evidence to support an estimate of a difference between "Present" and "Future" yields, the same values should be used in these respective spaces.

It should be stated on the form that sedimentation surveys were used to develop the values. The source of the data and the work sheets used in developing the information should be filed with the form.

c. Data from Suspended Load Records

Sediment yield information obtained and transposed from suspended load stations is entered on the form in the same manner as that obtained from reservoir sedimentation surveys. A statement that suspended load records were used should be placed on the form. The supporting data, including a listing of the stations used, should be filed with the form.

d. Data Developed by Direct Predictive Equations

If a predictive equation to determine sediment yield is used, the computed value of the sediment yield is to be entered in the appropriate spaces for total "Tons Delivered." The equation used should be noted on the form, and the work sheets involved in the solution of the equation should be filed with it.

An example of this part of the form follows.

SEDIMENT YIELD BY SOURCES (AVERAGE ANNUAL)

		PRESENT CONDITIONS			FUTURE (AFTER CONS. TREATMENT)		
		ACRES	SOIL LOSS (TONS/AC)	TOTAL (TONS)	ACRES	SOIL LOSS (TONS/AC)	TOTAL (TONS)
SHEET EROSION	CULTIVATED LAND 1/	540	18.5	9990 2/	500	12.9	6450 2/
	IDLE LAND	150	8.1	1215			
	PASTURE - RANGE	880	4.1	3610	950	2.9	2755
	WOODLAND	630	2.3	1450	750	1.5	1125
	OTHER						

	PRESENT: DELIVERY RATIO (%)		PRESENT: TONS DELIVERED	FUTURE: DELIVERY RATIO (%)		FUTURE: TONS DELIVERED
SHEET EROSION - TOTAL	20	16265	3255 2/	20	10330	2065 2/
GULLY EROSION	80	6600	5280	80	3160	2530
STREAMBANK EROSION	90	1200	1080	90	1200	1080
STREAMBED EROSION						
FLOODPLAIN SCOUR						
OTHER (ROADSIDE ETC.)	50	2000	1000	50	800	400
		TOTAL	10615 3/		TOTAL	6075 4/

1/ Includes row crops, small grains, meadow.

2/ Product of preceding two columns rounded to nearest five tons.

3/ To be entered under column "Sediment Delivered to Site" in "Present" space of "Deposition" part of form.

4/ To be entered under column "Sediment Delivered to Site" in "Future" space of "Deposition" part of form. This will be entered in one or both "Future" spaces depending upon the type and design life of the structure.

3. Texture and Volume Weight

The estimated texture of the incoming sediment is to be entered in the spaces provided. The volume weight, in pounds per cubic foot, for submerged and aerated deposited sediment is based on the estimated texture and the guidelines presented in the table on page 9. These values are entered in the appropriate spaces on the form.

4. Deposition

This part of the form is provided to compute the amount of sediment delivered to the site that will deposit in the reservoir. Three lines are provided to facilitate computations of sediment deposition in two 50-year periods. The first two lines, indicated as "Present" and Future," are used for the first 50-year period, and the third line, indicated as "Future," is used for the second 50-year period. For a single-purpose floodwater retarding structure with a design life of 50 years or for a multiple-purpose structure with a design life of either 50 or 100 years, entries need be made only in the first two lines. Each column in this part of the form is discussed below.

a. Sediment Delivered to Site (Tons/Yr)

The values for the sediment yield, the total "Tons Delivered" previously computed, are entered in the appropriate spaces "Present" and "Future."

To allow for the gradual improvement of watershed conditions during the period of installation of land treatment measures and the period during which these measures become effective in reducing erosion, an average sediment yield between the calculated present and future rates may be used for the "Present."

b. Trap Efficiency

The trap efficiency is estimated on the basis of the discussions presented on pages 5 and 6. The value is entered in this column. There is insufficient data available at this time to predict the change in trap efficiency with increasing life of a reservoir. Therefore the same value for the trap efficiency of a given reservoir should be used for both present and future conditions.

c. Annual Deposition (Tons)

The "Annual Deposition (Tons)" is the product of "Sediment Delivered to Site (Tons/Yr)" and the "Trap Efficiency (%)" for each line.

d. Design Period (Yrs)

The "Design Period" for "Present" conditions is the anticipated number of years that will be required for the proposed land treatment measures to be installed and become fully established and effective in reducing erosion and sediment yield.

The "Design Period" for the second line, indicated as "Future," for a single-purpose floodwater retarding structure with a 100-year design life will be the difference between 50 years and the "Design Period" for "Present" conditions. The "Design Period" for the third line, indicated as "Future," is the remaining design life of the structure. In the instance of a 100-year life single-purpose floodwater retarding structure, this is 50 years. Provision is thus made for two 50-year periods.

In the instance of a structure being designed for a 50-year life only the first two lines of this part of the form are used. Similarly, for a multiple-purpose structure with a design life of 100 years, the first two lines are the only ones to be used. In this latter instance, the "Design Period" for the "Future" would be the difference between 100 years and the "Design Period" for "Present" conditions.

e. Period Deposition (Tons)

The "Period Deposition" is the product of the "Annual Deposition" and the corresponding number of years for each "Design Period."

f. Design Deposition (Tons)

The column "Design Deposition" when completed provides the information needed to determine sediment storage requirements. The first open space in this column is provided to enter the sum of the values noted in the first two spaces under "Period

Deposition." The values to be entered in the second open space of this last column will equal the value recorded in the third space of the preceding column. This makes available for further computations the amount of deposition expected to occur in each of the two 50-year periods necessary for consideration in the sediment design of a 100-year life single-purpose floodwater retarding structure.

The "total" space of this last column is the sum of the values for the two (if used) "Design Deposition" values. This sum represents the total amount of sediment, in tons, that will be deposited in the reservoir during the designed effective life of structure.

As noted earlier, direct predictive equations may be used to determine sediment yields. In some instances predictive equations are developed to estimate the total deposition, in tons, within a reservoir during a period of time. The sediment yield, trap efficiency, and life of the reservoir generally are among the variables incorporated in such equations. If such an equation is used, it is necessary to enter only the estimated deposition for the required time periods in the last column of this part of the form.

The following examples illustrate the use of this part of the form for several different situations.

(1) 50-Year Life Reservoir--Any Purpose

1/

TEXTURE INCOMING SEDIMENT		
% CLAY	% SILT	% COARSE
30	40	30
VOLUME WEIGHT DEPOSITED SEDIMENT LBS/CU. FT.		
SUBMERGED	50	
AERATED	82	

DEPOSITION

	2/	3/	4/	5/	6/	
SEDIMENT DELIVERED TO SITE (TONS/YR)		TRAP EFFICIENCY (%)	ANNUAL DEPOSITION (TONS)	DESIGN PERIOD (YRS)	PERIOD DEPOSITION (TONS)	DESIGN DEPOSITION (TONS)
PRESENT	10615	95	10085	8	80680	
FUTURE	6075	95	5770	42	242340	323020[7/]
FUTURE						
			TOTALS	50		323020[8/]

1/ See item 3 on page 15.

2/ Entries from "Sediment Yield" part of form.

3/ See item 4b on page 16.

4/ Product of 2/ and 3/ to nearest five tons.

5/ See item 4d on page 16.

6/ Product of 4/ and 5/.

7/ Sum of values entered in the first two spaces of 6/.

8/ To be used in "Sediment Storage Requirements" part of form.

(2) 100-year life reservoir - single-purpose floodwater retarding reservoir.

TEXTURE INCOMING SEDIMENT		
% CLAY	% SILT	% COARSE
30	40	30
VOLUME WEIGHT DEPOSITED SEDIMENT LBS/CU. FT.		
SUBMERGED		50
AERATED		82

DEPOSITION

	SEDIMENT DELIVERED TO SITE (TONS/YR) 1/	TRAP EFFICIENCY (%)	ANNUAL DEPOSITION (TONS)	DESIGN PERIOD (YRS) 2/	PERIOD DEPOSITION (TONS)	DESIGN DEPOSITION (TONS)
PRESENT	10615	95	10085	8	80680	
FUTURE	6075	95	5770	42	242340	323020 3/
FUTURE	6075	95	5770	50	288500	288500 4/
			TOTALS	100		611520

1/ Entries from "Sediment Yield" part of form.

2/ See item 4d on page 16.

3/ This value to be used in first 50-year period for distribution in "Sediment Storage Requirements" part of form.

4/ This value to be used for second 50-year period for distribution in "Sediment Storage Requirements" part of form.

(3) 100-year life reservoir - multiple purpose.

TEXTURE INCOMING SEDIMENT		
% CLAY	% SILT	% COARSE
30	40	30
VOLUME WEIGHT DEPOSITED SEDIMENT LBS/CU. FT.		
SUBMERGED		50
AERATED		82

DEPOSITION

	SEDIMENT DELIVERED TO SITE (TONS/YR) 1/	TRAP EFFICIENCY (%)	ANNUAL DEPOSITION (TONS)	DESIGN PERIOD (YRS) 2/	PERIOD DEPOSITION (TONS)	DESIGN DEPOSITION (TONS)
PRESENT	10615	95	10085	8	80680	
FUTURE	6075	95	5770	92	530840	611520
FUTURE						
			TOTALS	100		611520 3/

1/ Entries from "Sediment Yield" part of form.

2/ See item 4d on page 16.

3/ This total to be used for distribution for entire 100-year period in "Sediment Storage Requirements" part of form.

5. Sediment Storage Requirements

This part of the form is used for estimating the distribution and allocation of required capacity for sediment accumulation in the various pools to be included in the reservoir.

a. Period (Yrs)

This column provides for the two periods of time needed to develop the sediment design for a single-purpose floodwater retarding reservoir with a 100-year life. In the first space, in this instance, would be noted "first 50 years" and in the second space would be noted "second 50 years." For any structure being designed with a 50-year life, only the first space would be used and "50 years" would be noted therein. Similarly, for a multiple-purpose reservoir being designed with a 100-year

life, only the first space would be used and "100 years" would be noted therein.

b. Condition of Sediment

This column is self-explanatory and provides headings indicating the expected condition of the sediment, whether submerged or aerated, for use in the computation.

c. Percent (%) of Total

This column makes provisions to enter values for the estimated protions of the incoming sediment that will deposit in submerged and aerated environments during the periods being considered. The values used should be in conformance with the guidelines previously discussed.

There is little information available that will predict differences in the environment of sediment deposition within a reservoir with its increasing age. Therefore it is suggested that the same percentages be used during the entire design life of the reservoir. For a 100-year life single-purpose floodwater retarding reservoir, this would mean using the same percentage distribution for each of the two 50-year periods.

d. Deposition (Tons)

This fourth column provides the spaces to enter the amounts of the estimated sediment deposition, in tons, previously determined in the "Deposition" part of the form. The total "Design Deposition" as previously determined is entered in the "Total" space of this column. In the instance of a single-purpose floodwater retarding reservoir with a design life of 100 years, the same "Design Deposition" is entered in the "Total" space of this column. However, the "Design Deposition" previously computed and entered in the first and second spaces of the last column of the "Deposition" part of the form must be used for the first 50-year period and the second 50-year period, respectively. No spaces for recording these values are provided in this part of the form, and a separate worksheet will be necessary to facilitate the computation.

The "Design Deposition" values are multiplied by the corresponding percentage values of the preceding column to arrive at the number of tons of sediment expected to be deposited under submerged and aerated conditions. These values are entered in the appropriate spaces of this fourth column.

e. Volume Weight (Tons/Ac. Ft.)

The tons of sediment deposited in the reservoir must be expressed in terms of the volume it will displace. The volume weight entered in the small box "Volume Weight, Deposited Sediment

(lbs/cu.ft.)" is converted to tons per acre foot by the following equation:

$$\text{Tons/Ac.Ft.} = \text{lbs/cu.ft.} \times 21.78$$

The conversions for both submerged and aerated sediment are made and the values entered in the corresponding spaces of this column.

f. Storage Required

(1) The acre-feet of storage required is obtained by dividing the "Deposition (Tons)" by the corresponding "Volume Weight (Tons/ac.ft.)" for each condition of sediment. The sum of the values in this column is the total capacity required in the reservoir for sediment storage. The values recorded in the individual spaces in this column are distributed among the various pools indicated in the last three columns of this part of the form.

(2) The column "Watershed Inches" is used to express the acre-feet of sediment shown in the sixth column in equivalent watershed inches. The values are obtained by the equation:

$$\text{Watershed Inches} = 0.01875\left(\frac{\text{acre feet of sediment storage}}{\text{drainage area in square miles}}\right)$$

g. Storage Allocation

As stated earlier, the required sediment storage must be allocated between the various pools in the reservoir. The guidelines previously presented indicate how these allocations are to be considered.

Where equations have been developed to predict the total sediment accumulation, in acre-feet, expected in a reservoir during its entire life, the results may be entered in the total "Storage Required" space of the form. Storage allocations can be made from this value. In some instances these equations will predict the distribution and allocation of the deposited sediment. In such cases the information may be used, and the predicted allocations should be entered in the appropriate spaces of the form. The use of such equations should be noted on the form and any work sheets used in the computation should be filed with it.

The following examples are presented to facilitate an understanding of the completion of the "Sediment Storage Requirements" part of the form.

1. Single-purpose floodwater retarding reservoirs

    a. Single-stage principal spillway

(1) 50-year design life

SEDIMENT STORAGE REQUIREMENTS

PERIOD (YRS) 1/	CONDITION OF SEDIMENT 2/	% OF TOTAL 2/	DEPOSITION (TONS) 3/	VOLUME WEIGHT 4/	STORAGE REQUIRED 5/		STORAGE ALLOCATION (ACRE FEET) 6/		
				TONS/AC.FT.	ACRE-FEET	WATERSHED INCHES	SEDIMENT POOL	RETARDING POOL	OTHER
50	SUBMERGED	80	258,415	1089	237.3	1.29	237.3		
	AERATED	20	64,605	1786	36.2	0.20		36.2	
	SUBMERGED								
	AERATED								
50	TOTALS		323,020		273.5	1.49	237.3 7/	36.2 8/	

1/ See discussion on page 6 and item 4d on page 16.

2/ See discussion on page 8.

3/ See item 5d on page 19.

4/ See item 5e on page 19.

5/ See item 5f on page 20.

6/ Guidelines given on pages 9-12.

7/ This capacity establishes the crest elevation of the principal spillway.

8/ This capacity must be added to the required floodwater retarding volume to establish the elevation of the emergency spillway.

(2) 100-year design life

SEDIMENT STORAGE REQUIREMENTS

PERIOD (YRS)	CONDITION OF SEDIMENT	% OF TOTAL 1/	DEPOSITION (TONS)	VOLUME WEIGHT	STORAGE REQUIRED		STORAGE ALLOCATION (ACRE FEET)		
				TONS/AC.FT.	ACRE-FEET	WATERSHED INCHES	SEDIMENT POOL	RETARDING POOL	OTHER
1st 50 yrs.	SUBMERGED	80	258,415	1089	237.3	1.29	237.3 2/		
	AERATED	20	64,605	1786	36.2	0.20	25.4 3/	10.8	
2nd 50 yrs.	SUBMERGED	80	230,800	1089	211.9	1.16	211.9		
	AERATED	20	57,700	1786	32.3	0.18		32.3	
100	TOTALS		611,520		517.7	2.83	474.6 4/	43.1 5/	

1/ See item 5c on page 19.

2/ Establishes crest elevation of principal spillway for first 50-year period.

3/ Deposited in second 50-year sediment pool (sediment reserve) during first 50-year period.

4/ Establishes crest elevation of principal spillway for second 50-year period.

5/ This capacity must be added to the required floodwater retarding volume to establish the elevation of the emergency spillway.

b. Two-stage principal spillway

(1) 50-year design life

SEDIMENT STORAGE REQUIREMENTS

PERIOD (YRS)	CONDITION OF SEDIMENT	% OF TOTAL	DEPOSITION (TONS)	VOLUME WEIGHT	STORAGE REQUIRED		STORAGE ALLOCATION (ACRE FEET)		
				TONS/AC.FT.	ACRE-FEET	WATERSHED INCHES	SEDIMENT POOL	RETARDING POOL	OTHER 1/
50	SUBMERGED	80	258,415	1089	237.3	1.29	237.3		
	AERATED	20	64,605	1786	36.2	0.20		10.8	25.4
	SUBMERGED								
	AERATED								
50	TOTALS		323,020		273.5	1.49	237.3 2/	10.8 3/	25.4 4/

1/ Retarding pool between low and high stage inlets.

2/ Establishes crest elevation of low stage inlet.

3/ This volume must be added to required retarding capacity above the elevation of the high stage inlet to establish the elevation of the emergency spillway.

4/ This volume must be added to required retarding capacity between the low and high stage inlets to establish the elevation of the high stage inlet.

(2) 100-year design life

SEDIMENT STORAGE REQUIREMENTS

PERIOD (YRS)	CONDITION OF SEDIMENT	% OF TOTAL	DEPOSITION (TONS)	VOLUME WEIGHT	STORAGE REQUIRED		STORAGE ALLOCATION (ACRE FEET)		
				TONS/AC.FT.	ACRE-FEET	WATERSHED INCHES	SEDIMENT POOL	RETARDING POOL	OTHER 1/
1st 50 yrs.	SUBMERGED	80	258,415	1089	237.3	1.29	237.3 2/		
	AERATED	20	64,605	1786	36.2	0.20	17.8 3/	10.8	7.6
2nd 50 yrs.	SUBMERGED	80	230,800	1089	211.9	1.16	211.9		
	AERATED	20	57,700	1786	32.3	0.18		12.9	19.4
100	TOTALS		611,520		517.7	2.83	467.0 4/	23.7	27.0 5/

1/ Detention capacity between low and high stage inlets.

2/ Establishes crest elevation of low stage inlet at 50 years.

3/ Deposited in second 50-year sediment pool (sediment reserve) during the first 50 years.

4/ Establishes crest elevation of low stage inlet at 100 years.

5/ Deposited in retarding pool between low and high stage inlets at end of 100 years.

Note: The sum of the values in 4/ and 5/ plus the required floodwater retarding capacity between the low and high stage inlets establishes the elevation of the high stage inlet at 100 years to be provided in the original construction plans.

2. Multiple-Purpose Reservoir - 100-year design life

SEDIMENT STORAGE REQUIREMENTS

<table>
<tr><th rowspan="2">PERIOD (YRS)</th><th rowspan="2">CONDITION OF SEDIMENT</th><th rowspan="2">% OF TOTAL</th><th rowspan="2">DEPOSITION (TONS)</th><th>VOLUME WEIGHT</th><th colspan="2">STORAGE REQUIRED</th><th colspan="3">STORAGE ALLOCATION (ACRE FEET)</th></tr>
<tr><th>TONS/AC.FT.</th><th>ACRE-FEET</th><th>WATERSHED INCHES</th><th>SEDIMENT POOL</th><th>RETARDING POOL</th><th>OTHER 1/</th></tr>
<tr><td rowspan="2">100</td><td>SUBMERGED</td><td>80</td><td>489,215</td><td>1089</td><td>449.2</td><td>2.45</td><td>382.2</td><td></td><td>67.0 2/</td></tr>
<tr><td>AERATED</td><td>20</td><td>122,305</td><td>1786</td><td>68.5</td><td>0.37</td><td></td><td>68.5</td><td></td></tr>
<tr><td rowspan="2"></td><td>SUBMERGED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>AERATED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>100</td><td colspan="2">TOTALS</td><td>611,520</td><td></td><td>517.7</td><td>2.82</td><td>382.2 3/</td><td>68.5</td><td>67.0 4/</td></tr>
</table>

1/ Beneficial water storage.

2/ Portion of submerged sediment allocated to beneficial storage pool to be based on the judgment of the geologist in consultation with the Engineering and Watershed Planning Unit.

3/ Submerged sediment in sediment pool.

4/ Submerged sediment deposited in capacity for beneficial use.

Note: The required capacity for beneficial use must be added to the sum of 3/ and 4/ to establish the crest elevation of the principal spillway.

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